

VECTOR DIAGRAM OF THE CHEMICAL COMPOSITIONS  
OF TEKTITES AND EARTH LAVAS

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/193\*

The chemical compositions of tektites (natural silica glasses) have been compared with the chemical compositions of obsidians, igneous and sedimentary rock by a number of researchers using a variety of methods (see V. E. Barnes, 1940; G. Baker, 1959; W. F. Cassidy, 1958).

Our aim was to compare the chemical compositions of tektites and various volcanic glasses, similar in composition to tektites, by the petrochemical method of A. N. Zavaritskiy (1941, 1944, 1950). The advantage of this method is that a large number of chemical analyses of igneous rocks can be graphically compared with the help of vectors, plotted in relation to six parameters. These parameters, calculated from ratios of the main oxides given by silicate analysis, reflect the chief characteristics of igneous rock.

Material for the study was supplied by data from chemical analyses characterizing tektites of all known locations (Table 1) and data from chemical analyses of obsidians similar in chemical composition to tektites of various petrographical provinces (Table 2).

Fig. 1 shows the vector diagram plotted from numerical characteristics converted from chemical analysis data (Tables 1 and 2).

As can be seen from the diagram and tables, the majority of starting points of vectors are located along the SB axis or near it and a band of almost constant width is formed. The range and shape of the vector cluster as a whole specify the chemical composition of tektites as strongly supersaturated and supersaturated with silica, as well as very poor and poor in alkalis ( $a$  is not over 4). The length and direction (sloped to the left) of the vectors specify them as supersaturated with silica with a relatively high basicity, fluctuating in wide limits ( $b$  from 5 to 15).

Five vectors deviate from the general band in high alkalinity - 1 indochinite, 2 billitonite, 1 javaite and 1 americanite (inclusion of the latter

\*Numbers in margin indicate pagination in original foreign text.

among tektites proper is subject to doubt).

The cluster of vectors for chemical compositions of tektites from various locations is gradually shifted along the SB axis and forms fields which partially overlap, but not sharply isolated groups. These fields are shifted in the following order of increasing basicity: Vltavins (moldavites) — indochinites and australites — billitonites — bediasites — Ivory Coast tektites.

We must note the group of vltavins (moldavites) distinguished by the prevalence of potassium among alkalis.

/201

The variation curve of the chemical compositions of tektites (TT), determined by the position of initial points of vectors, is characterized by its proximity to the SB axis and its weak slope toward this axis. It proceeds lower (from point A) to the variation curve of feldspar achondrites (see L. G. Kvasha, 1958, 1959) which are distinguished by the same character.

Earth lavas in a petrochemical respect have been quite well investigated. Their analyses number in the thousands. The initial points of vectors, representing their chemical compositions, form very definite bands. These bands, reflecting change in the composition of lavas during the course of normal crystallization-gravitation differentiation of magma, can be expressed in variation curves. A certain variation curve corresponds to each type of lava.

In Fig. 1 is plotted the variation curve of chemical compositions of lavas from Japanese volcanos (JJ), converted to the variation curve of chemical compositions of Pelee type lavas, according to the method of A. N. Zavaritskiy (1950). It represents calc-alkali lavas of island chains and is closest to the SB axis of all variation curves of earth lavas. Numerical characteristics of average types of Japanese lavas, according to the data of S. Taneda (1952) are given in Table 3.

The vector cluster of obsidians is located to the right of the variation curve JJ close to the SA axis and is slightly elongated in the direction of this axis. This cluster shape indicates significant fluctuations of alkalinity in obsidians, as they belong to various petrochemical associations. The length and direction of the majority of vectors correspond to the normal type of chemical compositions (sloped toward the right); about 1/3 of the vectors show a sharp slant to the right, i.e. potassium predominates in their femic part (flatter vectors). However, about 1/4 of the total number of vectors

Table 1

No.	Tektites and their locations	Numerical characteristics*										Q	a/c	Source (second is analyst)				
		main					secondary											
		a	c	b	s	a'	f'	m'	c'	n	t							
<b>Vltavins (moldavites)</b>																		
Czech.																		
1	Bohemia	3.2	3.2	5.1	88.5		42.3	57.7		0		67.4	1	J. Hanemann (1894)				
2	" "	5.6	2.4	5.8	86.2	26.3	29.5	44.2		13.6	0.3	58.8	2.38	R. Nováček (1932)				
3	Moravia	5.3	2.2	6.0	86.5	40	15	45		19.5	0.66	60.2	2.4	A. Lacroix (1932)				
4	Bohemia	4.4	4.1	6.0	85.5		35	60	5	18.6	0.3	58.1	1.0	F. Raoult R. Novacek (1932)				
5	Cheske- Budejovice	4.3	2.4	6.3	87.0	44.5	18.2	37.4		29.0	0.66	63.0	1.75	C. John (1899)				
6	Bohemia	5.6	2.0	7.2	85.2	38.5	29.0	32.5		22.0	57.2	57.2	2.8	A. Lacroix (1932)				
7	" "	3.3	2.4	7.6	86.7	56.1	23.2	20.7		11.5		64.4	1.4	F. Raoult C. John (1889)				
8**	Moravia	5.1	2.8	7.6	84.5	42.5	22.0	35.0		20	0.37	56.0	1.7	R. Nováček (1932)				
9	Bohemia	4.3	3.5	7.7	84.5	65.4	30.4	4.2		15		56.9	1.23	C. John (1889)				
10	Moravia	6.8	1.3	8.5	83.4	58.9	22.5	18.6		21.5	0.5	51.9	5.2	R. Nováček (1932)				
11	" "	5.7	1.4	10.2	82.7	55.2	22.1	22.7		24	1.35	52.6	4.1	A. Lacroix (1932)				
Indochinites																		
Indochina and So. China																		
15	Cambodia	6.6	0.8	7.3	85.3		57.6	28.8	13.6	52	1.0	56.6	8.2	A. Lacroix (1935)				
16	VietNam	6.6	3.0	7.5	82.9	46.8	0.4	52.8		55	0.9	49.6	2.2	F. Raoult A. Lacroix (1935)				

Table 1 (continuation)

Tektites No. and their locations	Numerical characteristics*											Q	a/c	Source (second is analyst)			
	main					secondary											
	a	c	b	s	a'	f'	m'	c'	n	t							
17 So. China, Haitan	6.9	5.2	8.6	79.3		57.0	36.1	6.9	45	1.1	39.6	1.25	A. Lacroix (1930) F. Raoult				
18*** Cambodia	8.9	2.8	9.3	79.0	12	45	43		57	0.8	37.4	3.1	A. Lacroix (1929) F. Raoult				
19** Laos	7.4	3.6	9.9	78.8	15.4	52.0	32.6		47	1.1	39.5	2.1	A. Lacroix (1930) F. Raoult				
20 Thailand (Siam)	8.1	0.3	9.9	81.7		36.1	34.7	29.2	45	0.7	46.9	2.7	C. M. Koomans (1938)				
21 Malacca	7.6	4.1	10.0	78.3	18.6	46.0	34.5		56.5	0.8	37.3	1.8	A. Lacroix (1932) F. Raoult				
22** Laos	7.2	3.2	10.2	79.4	25.5	41.5	33.0		50	1.1	41.2	2.2	A. Lacroix (1935) F. Raoult				
23 Thailand	6.9	2.9	10.4	79.8	33.5	43.8	22.7		57.4	0.8	42.9	2.4	A. Lacroix (1935) F. Raoult				
24 So. China	5.2	3.8	11.0	80.0	28.6	41.7	29.7		50.2	1.0	45.8	1.4	A. Lacroix (1935) F. Raoult				
25 Cambodia	7.1	2.6	11.4	78.9	27.3	41.5	31.2		60	0.9	41.0	2.7	A. Lacroix (1935) F. Raoult				
26** Viet Nam	6.3	2.6	12.2	78.9	29.3	39.8	30.9		53	1.05	42.6	2.5	A. Lacroix (1935) F. Raoult				
27 So. China	6.0	3.5	12.3	78.2	36.6	37.2	30.9		50	1.0	40.9	1.7	A. Lacroix (1935) F. Raoult				
28 Viet Nam	5.7	2.6	15.9	75.8	31.4	52.2	16.4		51	0.9	37.6	2.2	A. Lacroix (1935) F. Raoult				
Australites																	
Australia and Tasmania																	
29 Northern Australia	5.4	2.8	7.8	84.0	21.4	46.0	32.6		50	0.8	54.4	1.9	H. S. Summers (1909) G. A. Ampt				
30 Tasmania	4.9	3.4	8.4	83.3		48.4	36.3	15.3	44	0.7	63.4	1.44	F. W. Clarke (1904) W. F. Hillebrand				

Table 1 (continuation)

No.	Tektites and their locations	Numerical characteristics*										Q	a/c	Source (second is analyst)			
		main					secondary										
		a	c	b	s	a'	f'	m'	c'	n	t						
Australites Australia and Tasmania																	
31	Victoria	4.9	3.0	9.6	82.5	36.0	39.4	24.6		50	0.6	52.2	1.6	H. S. Summers (1909) G. A. Ampt			
32	" "	5.7	3.7	11.5	79.1	31.7	40.6	27.7		54	0.8	43.1	1.5	H. S. Summers (1909) G. A. Ampt			
33	Western Australia	5.7	3.5	13.3	77.5	32.5	38.6	28.9		48	0.9	40.1	1.6	A. Lacroix (1932) A. Hall			
34	Tasmania	6.5	3.7	14.0	75.8	37.7	33.7	28.6		43	0.8	34.9	1.8	W. F. Hillebrand (1910)			
Billitonites Billiton, Java, Borneo																	
35	Billiton	9.0	3.0	9.0	79.0		57	43		57		37	3	R. D. Verbeek (1897) Brunck			
36	" "	6.8	4.7	10.8	77.7	4.9	55.5	39.6		53	1.2	37.1	1.4	A. Lacroix (1930) F. Raoult			
37	" "	8.6	3.5	10.9	77.0		53.5	38.7	7.8	60		32.7	2.4	F. E. Suess (1900) C. John			
38	Java	5.4	2.9	11.7	80.0	25.4	40.0	34.6		43	0.9	46.3	1.8	F. Heide (1939) P. Wagner			
39	"	5.7	3.4	13.8	77.1	23.5	42.0	34.5		61	0.6	39.4	1.6	C. M. Koomans (1938) F. Raoult			
40	Borneo	14.3	1.4	14.2	70.1		31.0	41.5	27.5	82.7	1.1	27.2	10.2	A. Lacroix (1932) F. Raoult			
41	" "	6.2	2.6	14.7	76.5	38.5	35.8	25.7		51	1.1	38.0	2.4	F. P. Müller (1945) Hinden			

Table 1 (continuation)

No.	Tektites and their locations	Numerical characteristics*										Q	a/c	Source (second is analyst)			
		main					secondary										
		a	c	b	s	a'	f'	m'	c'	n	t						
Philippinites, Rizalites Philippines																	
42	Luzon	6.8	4.7	9.3	79.2		52.8	46.5	0.7	51	0.9	40.1	1.4	T. Hodge-Smith (1932) H. P. White			
43**	"	5.9	4.1	11.2	78.8	31	37	32		57	0.8	41.7	1.4	C. M. Koomans (1938)			
44**	"	5.6	3.9	11.9	78.6	21.0	40.9	38.1		44	1.8	36.5	1.4	A. Lacroix (1931) F. Raoult			
45	"	6.1	3.4	11.9	78.6	23.3	37.0	39.7		57.5	1.8	41.6	1.8	C. M. Koomans (1928)			
46**	"	6.2	3.2	12.2	78.4	26.6	37.7	35.7		48	1.0	41.2	1.9	F. Heide (1938) P. Wagner			
47	"	5.8	3.4	14.2	76.6	19.2	40.2	40.6		58	0.6	38.2	1.7	C. M. Koomans (1938)			
Americanites So. America,																	
48	Peru	11.8	0.9	13.3	74.0	91.8	6.7	1.5		60.1	23	23.5	14.2	G. Linck (1926)			
Ivory Coast Tektites Western Africa																	
49	Ivory Coast	3.7	1.8	15.2	79.3	41	23	36		70	0.6	49.4	2.0	A. Lacroix (1934) F. Raoult			
50	" "	7.1	1.6	18.9	72.4	45.4	30.8	23.8		61.7	0.9	29	4.4	A. Lacroix (1934) F. Raoult			
51	" "	5.2	2.2	21.2	71.4	49.7	25.4			55	0.9	30.2	2.35	A. Lacroix (1940) F. Raoult			

Table 1 (continuation)

No.	Tektites and their locations	Numerical characteristics*									Q	a/c	Source (second is analyst)	
		main				secondary								
		a	c	b	s	a'	f'	m'	c'	n	t			
Bediasites, North America														
52	Texas, USA	5.4	0	15.4	79.2	67.6	20.7	11.7			52	0.7	47.6	V. E. Barnes (1940)
53	" "	4.7	0.1	20.3	75.0	68.6	20.9	10.5			54	0.9	40.4	F. A. Gonyer (1940)
														V. E. Barnes (1940)
														F. A. Gonyer

- \* Numerical characteristics are arranged in order of increasing b within geographical groups.
- \*\* Vectors of chemical compositions of tektites No. 8, 13, 19, 22, 26, 43, 44 and 46, as respectively equal to the vectors of chemical compositions of tektites No. 6, 12, 21, 23, 27, 46, 24 and 32, 45, 26 and 27, are not plotted on the diagram.
- \*\*\* Vector of the chemical composition of tektite No. 18 is not plotted on the CSB plane as it is almost coincident with vectors No. 31 and 35.

Table 2

No.	Obsidians from various geographic regions	Numerical characteristics*									Q	a/c	Source
		main				secondary							
		a	c	b	s	a'	f'	m'	c'	n			
Islands of the Atlantic ocean													
1	Ascension	16.3	2.7	1.5	79.5		48	9	43	67	23.6	6.0	R. Reinisch (1912)
2	Canaries	15.6	1.2	4.1	79.1	22	67	11		54	25.8	13.0	K. Fritsch, W. Reiss (1868)
3	" "	26.0	1.3	4.4	69.3		93		7	73	15.7	20.0	K. Fritsch, W. Reiss (1868)
4	Azores	20.3	1.6	7.7	70.4	42	50	8		65	1.4	12.7	P. Esenwein (1929)

Table 2 (continuation)

No.	Obsidians from various geographic regions	Numerical characteristics*										Q	a/c	Source			
		main					secondary										
		a	c	b	s	a'	f'	m'	c'	n							
5	Canaries	20.5	1.9	12.2	65.4	20	75	5		72	12.1	10.8	K. Fritsch, W. Reiss	(1868)			
<i>Islands of the Mediterranean</i>																	
6	Sardinia (Monte Arci)	14.7	0.9	1.9	82.5	7	75	18		54	34.7	16.4	H. Washington	(1913 <sub>1</sub> )			
7	Lipari	15.8	0.5	2.2	81.5		82	3	15	56	30.9	31.6	A. Bergeat	(1900)			
8	"	15.4	0.4	2.4	81.8		76	8	16	56	32.0	38.6	A. Bergeat	(1900)			
9	"	14.6	0.8	3.0	81.6		71	11	18	56	33.2	18.2	A. Bergeat	(1900)			
10	Pantelleria	16.9	3.0	3.4	76.2		80	14	6	60	16.1	5.6	H. Washington	(1913 <sub>2</sub> )			
11	Vulcano	16.6	0	5.3	78.1		36	21	43	59	23.0	0	A. Lacroix	(1908)			
<i>Japan</i>																	
12	Hokkaido	12.6	2.3	2.0	83.1	14	48	38		51	38.7	5.5	T. Murase	(1958)			
13	Honshu	11.9	1.1	3.4	83.6	58	31	11		50	40.3	9.7	T. Murase	(1958)			
<i>No. America</i>																	
14**	Lake Mono	14.9	0.5	2.2	82.4		59	23	18	57	34.5	29.8	J. S. Diller	(1898)			
15	Yellowstone	12.9	1.3	2.9	82.9		21	62	17	55	38.7	9.9	A. Hague, J. P. Iddings, W. Weed, et al.	(1899)			
16	" "	13.9	0.9	3.4	81.8		53	38	9	60	34.9	15.5	A. Hague, J. P. Iddings, W. Weed, et al.	(1899)			
17**	" "	13.2	0.9	4.7	81.2		64	32	4	61	35.1	14.7	A. Hague, J. P. Iddings, W. Weed, et al.	(1899)			
18	" "	11.5	1.0	4.0	82.6		45	45	10	59	41.2	11.5	A. Hague, J. P. Iddings, W. Weed et al.	(1899)			

Table 2 (continuation)

No.	Obsidians from various geographic regions	Numerical characteristics*										Q	a/c	Source
		main					secondary							
		a	c	b	s	a'	f'	m'	c'	n				
Iceland														
19		12.8	32	2.5	82.5		62	11	27	66	37.2	5.8	F. Wolff	(1931)
20		13.0	1.9	4.0	81.1		38	10	52	75	34.3	6.8	F. Wolff	(1931)
21		17.1	1.0	5.2	76.6		64	18	18	64	18.2	17.1	F. E. Wright	(1915)
Africa														
22	Kenya	9.8	8.1	2.6	79.5		n'=67	5	28	48	31.3	1.2	A. Holmes, H. F. Harwood	(1936)
23	"	14.1	9.4	2.6	73.9		n'=8	24	68	52	10.2	1.4	A. Holmes, H. F. Harwood	(1936)
Asia														
24**	Armenia	16.8	0.4	2.5	80.3		67	10	23	59	26.6	42.0	A. S. Ginzberg	(1934)
25	Marekanka R. near Okhotsk	12.8	0.7	4.6	81.9	65	27	8		63	37.5	18.3	Unpublished analysis	
26	Caucasus	10.9	1.4	5.3	82.4	70	19	11		45	41.6	7.8	I. I. Tovarova	(1960)
													N. N. Chirvinskiy	(1934)

\* Numerical characteristics are arranged in order of increasing b within petrographical provinces coinciding with these geographical regions with the exception of obsidians No. 24, 25 and 26.

\*\* Vectors of chemical compositions of obsidians No. 14, 17, 24 on CSB plane are not plotted as they are coincident, respectively, with vectors of No. 7, 18, 8.

Table 3

10

Average types of lavas of Japan	Numerical characteristics										Source	
	main				secondary				Q	a/c		
	a	c	b	s	a'	f'	m'	c'				
Andesite	8.4	8.0	12.7	70.9	56	38	6	75	17	1.0	S. Taneda (1952)	
Dacite	9.1	6.7	8.2	76.0	66	34	0	72	27.1	1.4	S. Taneda (1952)	
Rhyolite	8.3	2.0	5.4	84.3	58	41	1	79	50	4.1	S. Taneda (1952)	

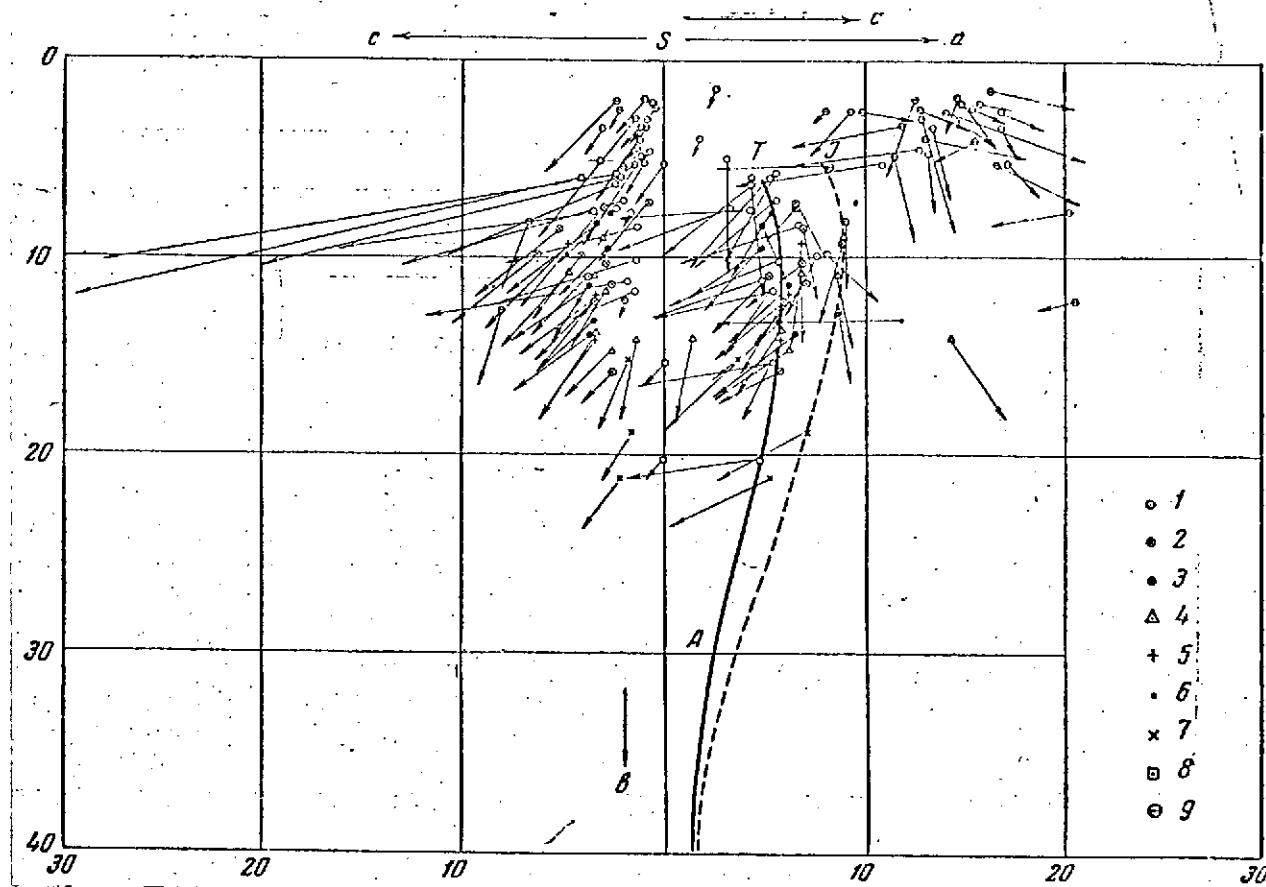


Fig. 1. Vector diagram of chemical composition of tektites and glass earth lavas  
 Legend: 1 - Vltavins (moldavites); 2 - indochinites; 3 - australites;  
 4 - billitonites; 5 - philippinites; \*

are related to compositions supersaturated with silica (vectors slope to the left).

From the diagram it is evident<sup>1</sup> that the vector fields of tektites and obsidians are clearly delimited and, what is more, the cluster of vectors of tektites is located to the left of the extreme variation curve of earth lavas representing a series of calc-alkali lavas of island chains. Further, the chemical compositions of tektites differ from those of obsidians in less alkalinity (their numerical characteristic  $a$  fluctuates between 4-6 while for obsidians it is usually over 8) and the predominant supersaturation with silica, even in more basic varieties. An increased  $TiO_2$  content is noted (parameter  $t$  about 1). In addition, the character of parameter  $b$  is generally more basic — from 5 to 15 (instead of 3-5 in obsidians), corresponding to dacites and andesites rather than liparites.

Analysis of the diagram leads to the conclusion that tektites are not earth lavas. Moreover, the variation curve of the chemical compositions of tektites, qualitatively similar to the closest variation curve of earth lavas, is a continuation of the variation curve of the chemical compositions of feldspar achondrites, forming a long series similar to the natural series of individual types of earth lavas. Therefore, tektites can be considered as products of crystallization-gravitation differentiation of feldspar achondrites, in their way lavas in the same way as obsidians and andesites are products of differentiation of earth basalts. In this case it must be assumed that tektites and achondrites originated in the same heavenly body of sufficient size, in which processes were occurring similar to the processes and phenomena of vulcanism on earth. /202

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<sup>1</sup>Only the ASB plane is considered, as in CSB projection the initial points of the vectors of tektites and obsidians form a combined field.

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\*Translator's Note: Illegible in the foreign text.

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